

Rapid loss of Paraguay's Atlantic forest and the status of protected areas — A Landsat assessment

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Abstract

Using Landsat images acquired since early 1970s, we have mapped the forest cover and change between 1989 and 2000, and estimated forest area in 1973 in Paraguay's Atlantic Forest Ecoregion (PAFE). The results revealed that as of 1973, 73.4% of the PAFE region was covered by forest. Since then, the proportion of forested area was quickly reduced to 40.7% by 1989 and further down to 24.9% by 2000. Two competing deforestation processes contributed to this rapid forest loss, with the first being driven by settlers and the second by large private land owners. During the 1989–2000 period, 80% of deforested areas were cleared by private land owners and 20% by the settlers. Protected areas slowed down forest loss within their boundaries, but not in their surrounding areas. The average percent forest loss in the area within 5 km from the boundary of Paraguay's major forested protected areas was 39% during the 1989–2000 period, which was essentially the same as that for the entire PAFE region during the same period. The high rates of forest loss in the areas surrounding the protected areas not only left the protected areas highly isolated as ecological "islands", they may also be precursors to rapid forest loss within the protected areas. These protected areas are critical to the conservation of many species endemic or limited to the PAFE region and surrounding areas, and should be continuously monitored using recent and future satellite observations.

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1. Introduction

The Atlantic forest in South America has been identified as one of the top priority ecosystems for global biological conservation (Myers, 1988; Olson & Dinerstein, 2002). The forest has extremely high levels of biodiversity, hosting an estimated 20,000 plant species and over 1300 non-fish vertebrate species (Mittermeier et al., 1999). The level of endemism is generally

high. More than 6000 plant species, 60% mammal species, 30% reptiles, and 90% forest amphibians are thought to be endemic, with many found nowhere else on the Earth (Mittermeier et al., 1999; Myers et al., 2000).

Much of the original Atlantic forest was in Brazil, spanning along the Atlantic coast from the northeast in the state of Rio Grande do Norte to the southernmost border, and extending inland to Argentina and Paraguay in the south. The vast majority of the original Atlantic forest in Brazil has disappeared. Estimates of remaining Atlantic forest in Brazil ranged from 1% to 12% (Saatchi et al., 2001). While the Atlantic forest in eastern Paraguay only accounts for a small portion of the geographic area of the Atlantic Forest ecoregion, it has an improporportionately high level of species diversity. The number of vascular

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plant species in eastern Paraguay was estimated at the order of 10,000 (Zardini, 1993), while the number of invertebrate species in Paraguay was around 100,000 (Catterson & Fragano, 2004). Many species endemic or limited to the Atlantic Forest have been documented in Paraguay, including 5 species of social wasps, 7 amphibian species, 11 reptile species, and 11 mammal species, with some found in Paraguay only (Fragano & Clay, 2003). Much of Paraguay's Atlantic forest remained "intact" before 1940, with the main form of deforestation being selective logging (Cartes, 2003). Since then, however, forest clearance became the major form of deforestation. Massive loss of Paraguay's forest resources has been reported since the 1970s, especially in eastern Paraguay (FAO, 1993, 2001; Sanjurjo & Gauto, 1996).

Using images acquired by the Landsat satellite series, we have systematically mapped the spatial extent of forest cover in 1989 and 2000 and the change between the two epochs for the entire country of Paraguay (Kim et al., submitted for publication), and estimated the total forest area within Paraguay's Atlantic Forest Ecoregion in the early 1970s using a systematic sampling approach. In this communication, we report on the status of Paraguay's Atlantic forest and its change since 1970s based on analysis of satellite observations, provide insight into the driving forces of the changes through analyzing the spatial patterns of mapped changes, and discuss the status of the protected areas in this region.

2. Data and methods

The study area was defined by intersecting Paraguay's country boundary with the Atlantic Forest Ecoregion developed by the World Wildlife Foundation (WWF) through the Global 200 project (Olson & Dinerstein, 2002). The resultant area of 85,502 km² will be referred to as Paraguay's Atlantic Forest Ecoregion (PAFE) hereafter. Nine spatially neighboring Landsat images were required to make a wall-to-wall coverage of the PAFE region. Three sets of Landsat images were used in this analysis. The first set consisted of Multi-Spectral Scanner (MSS) images having a nominal acquisition year of 1973. The second set consisted of Thematic Mapper (TM) images having a nominal acquisition year of 1989. The third set consisted of Enhanced Thematic Mapper Plus (ETM+) images having a nominal acquisition year of 2000. The pixel size of the MSS images was 57 m and that for TM and ETM+ images was 28.5 m. Table 1 lists the images used in this study.

The Landsat images were geometrically and radiometrically corrected using standard image preprocessing methods (Irish, 2000). Furthermore, the MSS and TM images were orthorectified to achieve high geolocation accuracy (Tucker et al., 2004). The ETM+ images were coregistered to TM images using manually collected ground control points. The residual coregistration error between the two sets of images was less than 0.5 pixel.

4. Discussions and conclusions

Using satellite images obtained since 1970s, we have mapped the spatial extent of Paraguay's Atlantic forests in nominal years 1989 and 2000 and their change between the two epochs, and estimated the total forest area within the PAFE region in the nominal year 1973. Mapped forest cover for the 2000 epoch was found highly reliable, with overall accuracy values being 93.9% and 97.5% in the two areas where a high resolution satellite image and aerial photos were available. The developed forest cover change map is publicly available from the Global Land Cover Facility at www.landcover.org. With wall-to-wall coverage and a high spatial resolution of 28.5 m, this product can be used in a wide range of conservation studies and applications in eastern Paraguay and the surrounding areas, including developing strategies for restoring biodiversity, identifying conservation hotspots and establishing wildlife corridors (Baydack et al., 1999).

Our results revealed that as of the early 1970s, 73.4% of the PAFE region was covered by forest. Since then, the proportion of forested area was quickly reduced to 40.7% by 1989 and further down to 24.9% by 2000. Paraguay lost nearly two thirds of its Atlantic forest between 1973 and 2000, a result mainly of two competing deforestation processes, one by the settlers and the other by the large land owners, with the latter being far more devastating. The developed forest cover change map for the 1989–2000 period revealed the status of protected areas. In general, the protected areas slowed down forest loss within their boundaries. While nearly 40% of Paraguay's Atlantic forests that existed in 1989 were lost by 2000, most protected areas, especially the non-public ones, only lost small proportions of their forest during the same period. The protected areas, however, did not slow down forest loss in their surrounding areas. The average percent forest loss between 1989 and 2000 in the area within 5 km from the boundary of the protected areas was 39%, which was essentially the same as that for the entire PAFE region during the same period.

The high rates of forest loss in the areas surrounding the protected areas can adversely impact the protected areas. Forests surrounding a protected area serve both as wildlife corridors and as a buffer zone shielding the protected area from being exploited (Cooperrider et al., 1999). Massive forest loss in the surrounding areas not only left the protected areas highly isolated as ecological "island", it may also be a precursor to rapid forest loss within the protected areas. Fig. 4 shows that the massive forest loss in the surrounding areas has penetrated into the Parque Nacional San Rafael. An analysis of forest change in Indonesia's protected areas revealed that some protected areas experienced rapid forest loss within their boundaries after massive forest loss within their surrounding areas (Curran et al., 2004). Therefore, Paraguay's protected areas may face imminent threats that can cause severe forest loss within their boundaries. These protected areas should be continuously monitored using recent and future satellite observations, as they are critical to the conservation of many species endemic or limited to the PAFE region and surrounding areas (Fragano & Clay, 2003).